

**CHAPTER 2**

**EPA/NSF ETV**

**EQUIPMENT VERIFICATION TESTING PLAN FOR**

**REMOVAL OF VOLATILE ORGANIC CHEMICALS BY**

**AIR STRIPPING TECHNOLOGY**

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## TABLE OF CONTENTS

	<u>Page</u>
<b>1.0 APPLICATION OF THIS VERIFICATION TESTING PLAN</b> .....	2-5
<b>2.0 INTRODUCTION</b> .....	2-5
<b>3.0 GENERAL APPROACH</b> .....	2-6
<b>4.0 OVERVIEW OF TASKS</b> .....	2-6
4.1 Task 1: Characterization of Feed Water .....	2-6
4.2 Task 2: Verification Testing .....	2-6
4.3 Task 3: Operating Conditions and System Performance .....	2-6
4.4 Task 4: Finished Water Quality .....	2-7
4.5 Task 5: Data Management .....	2-7
4.6 Task 6: QA/QC .....	2-7
4.7 Task 7: Effect of Scaling or Biofouling (Recommended) .....	2-7
<b>5.0 TESTING PERIOD</b> .....	2-7
<b>6.0 DEFINITIONS</b> .....	2-8
6.1 Feed water .....	2-8
6.2 Finished water .....	2-8
6.3 Packed Tower Aerator .....	2-8
6.4 Tray Aerator .....	2-8
6.5 Diffused Aeration .....	2-8
6.6 Spray Aerator .....	2-8
6.7 Membrane Air Stripper .....	2-8
6.8 Water Loading Rate or Liquid Loading Rate (L) .....	2-8
6.9 Air Loading Rate or Gas Loading Rate (G) .....	2-9
6.10 Air/Water Ratio (A/W) .....	2-9
6.11 Henry's Law Coefficient (H) .....	2-9
6.12 Stripping Factor (S) .....	2-9
6.13 Removal Efficiency .....	2-9
6.14 Channeling .....	2-9
6.15 Flooding .....	2-9
6.16 Biofouling .....	2-9
6.17 Scaling .....	2-9
<b>7.0 BACKGROUND INFORMATION ON AIR STRIPPING</b> .....	2-9

## TABLE OF CONTENTS (continued)

	<u>Page</u>
<b>8.0 TASK 1: CHARACTERIZATION OF FEED WATER</b> .....	2-11
8.1 Introduction .....	2-11
8.2 Experimental Objectives .....	2-11
8.3 Work Plan .....	2-11
8.4 Analytical Schedule .....	2-12
8.5 Evaluation Criteria and Minimum Reporting Requirements .....	2-13
<b>9.0 TASK 2: VERIFICATION TESTING</b> .....	2-13
9.1 Introduction .....	2-13
9.2 Experimental Objectives .....	2-14
9.3 Work Plan .....	2-14
9.4 Analytical Schedule .....	2-15
9.5 Evaluation Criteria and Minimum Reporting Requirements .....	2-15
<b>10.0 TASK 3: OPERATING CONDITIONS AND SYSTEM PERFORMANCE</b> ...	2-15
10.1 Introduction .....	2-15
10.2 Experimental Objectives .....	2-16
10.3 Work Plan .....	2-16
10.4 Evaluation Criteria and Minimum Reporting Requirements .....	2-16
<b>11.0 TASK 4: FINISHED WATER QUALITY</b> .....	2-16
11.1 Introduction .....	2-16
11.2 Experimental Objectives .....	2-16
11.3 Work Plan .....	2-17
11.4 Analytical Schedule .....	2-17
11.5 Evaluation Criteria and Minimum Reporting Requirements .....	2-18
<b>12.0 TASK 5: DATA MANAGEMENT</b> .....	2-18
12.1 Introduction .....	2-18
12.2 Experimental Objectives .....	2-18
12.3 Work Plan .....	2-18

## TABLE OF CONTENTS (continued)

	<u>Page</u>
<b>13.0 TASK 6: QUALITY ASSURANCE/QUALITY CONTROL</b> .....	2-19
13.1 Introduction .....	2-19
13.2 Experimental Objectives .....	2-19
13.3 Work Plan .....	2-19
13.4 On-Site Analytical Methods .....	2-19
13.4.1 Temperature .....	2-20
13.4.2 pH (Optional) .....	2-20
13.4.3 Turbidity (Optional) .....	2-20
13.4.4 Dissolved Oxygen (Optional) .....	2-20
13.5 Chemical and Biological Samples Shipped Off-Site for Analysis .....	2-21
13.5.1 VOCs .....	2-21
13.5.2 Chemical Analyses: Total Dissolved Solids, Alkalinity, and Hardness (Optional Parameters) .....	2-21
13.5.3 Chemical Analyses: Iron and Manganese (Optional Parameters) .....	2-21
13.5.4 Chemical Analysis: Total Sulfide (Optional) .....	2-21
13.5.5 Microbial Analysis: Heterotrophic Plate Count (Optional) .....	2-21
<b>14.0 TASK 7: EFFECT OF SCALING AND BIOFOULING (RECOMMENDED)</b> .....	2-22
14.1 Introduction .....	2-22
14.2 Experimental Objectives .....	2-22
14.3 Work Plan .....	2-22
14.4 Analytical Schedule .....	2-22
14.5 Evaluation Criteria and Minimum Reporting Requirements .....	2-22
<b>15.0 OPERATION AND MAINTENANCE MANUAL CRITERIA - AIR STRIPPING EQUIPMENT</b> .....	2-23
15.1 Maintenance .....	2-23
15.2 Operation .....	2-23
<b>16.0 REFERENCES</b> .....	2-23

## TABLES

Table 1 Required Analytical Parameters and Methods .....	2-12
Table 2 Recommended Analytical Parameters and Methods .....	2-13
Table 3 Testing Schedule and Methods for Verification Testing .....	2-15

## **1.0 APPLICATION OF THIS NSF EQUIPMENT VERIFICATION TESTING PLAN**

This document is the NSF Equipment Verification Testing Plan for Volatile Organic Compound (VOC) Removal by Air Stripping Technology Used in Packaged and/or Modular Drinking Water Treatment Systems for Small Public or Private Water Supplies. This Testing Plan is to be used as a guide in the development of the Field Operations Document for testing of air stripping equipment, within the structure provided by the NSF Protocol document for VOC removal. Refer to the "Protocol For Equipment Verification Testing For VOC Removal" for further information.

In order to participate in the equipment verification process for air stripping, the equipment Manufacturer and their designated Field Testing Organization shall employ the procedures and methods described in this test plan and in the referenced NSF Protocol Document as guidelines for the development of the Field Operations Document. The Field Operations Document should generally follow those Tasks outlined herein, with changes and modifications made for adaptations to specific air stripping equipment. As appropriate, the format of the procedures written for each Task should consist of the following sections:

- Introduction
- Objectives
- Work Plan
- Analytical Schedule
- Evaluation Criteria

Each Field Operations Document shall include Tasks 1 to 6 as identified below, with Task 7 being recommended but optional.

## **2.0 INTRODUCTION**

Air stripping involves the transfer of volatile aqueous contaminants from water to air. Air stripping, sometimes referred to as aeration, involves continuous contact of air with water to allow aqueous contaminants to transfer. The air is swept from the system, treated as necessary, and released to the atmosphere. The driving force for transfer of the contaminants is the difference between the concentration of the contaminant in untreated water and the concentration in water that is at equilibrium with the air.

This plan is applicable to any type of air stripping process as long as it is adequately described by the Manufacturer. Various air stripping processes are currently employed for water treatment applications including:

- packed tower, employing either structured or loose packing;
- shallow tray;
- diffused air;
- spray; and
- gas permeable hollow fiber membrane.

### **3.0 GENERAL APPROACH**

This NSF Equipment Verification Testing Plan is broken down into 7 tasks. As noted above, Tasks 1 to 6 shall be performed by any Manufacturer wanting the performance of their equipment verified by NSF. Task 7 is a recommended but optional task. The Manufacturer's designated Field Testing Organization shall provide full detail of the procedures to be followed in each Task in the Field Operations Document. The Field Testing Organization shall specify the operational conditions to be verified during the Verification Testing Plan.

The verification testing plan shall be performed in a series of short-term testing events for each operating condition to be verified. For surface water applications proper pretreatment must be applied as specified by the manufacturer. Testing shall be performed in the coldest period of the year. In addition, for each feed water tested a 30-day long-term testing period of continuous operation may be performed in the warmest period of the year to determine the effect of scaling and biofouling on the performance of the equipment.

Air stripping results in the transfer of VOCs from the feed water to air. Treatment of the air phase to meet applicable regulations may be necessary. Treatment of the air exiting the air stripping equipment is not considered part of this equipment verification, and thus a verification of equipment performance under this test plan does not constitute verification of any air treatment system.

### **4.0 OVERVIEW OF TASKS**

The following section provides a brief overview of the required tasks to be included in the air stripping verification testing program.

#### **4.1 Task 1: Characterization of Feed Water**

The objective of this task is to obtain a chemical, biological and physical characterization of the feed water. A brief description of the origin of the feed water shall be provided to aid in interpretation of these characteristics.

#### **4.2 Task 2: Verification Testing**

Water treatment equipment shall be operated under steady state conditions for at least eight hours per operational condition to be verified, during the coldest period of the year, to collect data on equipment performance and water quality for purposes of performance verification.

#### **4.3 Task 3: Operating Conditions and System Performance**

During each operational condition of Verification Testing, operating conditions and performance of the water treatment equipment shall be documented. Operating conditions include water loading rate, air loading rate, and water temperature. Equipment performance involves measurement of the air pressure drop and determination of potential precipitative scaling or biological fouling.

#### **4.4 Task 4: Finished Water Quality**

The objective of this task is to evaluate the quality of water produced by the air stripping process. Multiple water quality parameters will be monitored during the testing period. The mandatory water quality monitoring parameters shall include: temperature, calcium hardness, alkalinity, pH, dissolved oxygen and the VOCs to be treated. A basic goal of this Task is to confirm that treated waters meet Maximum Contaminant Limits (MCLs) for each VOC of interest, or to confirm percentage removal of a variety of VOCs with a range of Henry's Law coefficients (H). The latter goal will allow for extrapolation of performance verification under identical operating conditions to other VOCs based on H. Water quality produced will be evaluated in relation to feed water quality and operational conditions.

#### **4.5 Task 5: Data Management**

The objective of this task is to establish effective field protocol for data management at the field operations site and for data transmission between the Field Testing Organization and the NSF.

#### **4.6 Task 6: QA/QC**

An important aspect of verification testing is the protocol developed for quality assurance and quality control. The objective of this task is to assure accurate measurement of operational and water quality parameters during air stripping equipment verification testing.

#### **4.7 Task 7: Effect of Scaling or Biofouling (Recommended)**

This task is performed in order to determine the reduction in VOC removal efficiency as a result of precipitative scaling or biofouling of the air stripping media. This task should be performed over a 30-day period of continuous operation in the warmest period of the year.

### **5.0 TESTING PERIOD**

The required tasks of the NSF Equipment Verification Testing Plan (Tasks 1 through 6) are designed to be completed in one testing period, not including mobilization, shakedown and start-up. VOC removal verification shall be performed in the coldest period of the year. The effect of scaling and biofouling (recommended Task 7) should be performed in a 30-day period during the warmest period of the year.

Cold weather operations will be an important component of water quality testing for surface water sources because of the impact of cold temperatures (1° C to 5° C) on water viscosity, diffusional processes and contaminant volatility. In particular, for air stripping equipment, factors that can influence treatment performance include:

- Cold water, encountered in winter or at high altitude locations in mountainous regions of the country.

- Feed waters with high hardness, or iron which may promote precipitation of inorganic materials in the equipment, accelerating the need for chemical cleaning.

Warm weather long-term operation may also be an important component of performance testing because of the impact of warm temperatures on aqueous solubility and bioactivity. In particular, for air stripping equipment, factors that can influence long-term treatment performance include:

- Warm temperatures, encountered in summer, which increase the rate of bioactivity, resulting in increased biofouling. In general, the rate of bioactivity doubles with a 10°C increase in temperature.
- Warm temperatures also affect on the solubility of scalants. In most cases solubility decreases and scaling increases with an increase in water temperature.
- Feed waters with high total sulfur which may promote biofouling.

Each of the above may accelerate the need for chemical cleaning.

## 6.0 DEFINITIONS

**6.1 Feed water:** Water introduced to the air stripper.

**6.2 Finished water:** Water exiting the air stripper.

**6.3 Packed Tower Aerator:** A tower containing packing material which provides a large surface area for contact between water and air. Water is passed downflow through the tower and is broken into thin sheets and droplets while air flows up through the packing material. The packing material could be structured media grids, or loose packing which is poured into the column, and can be made of plastic, wood, ceramic, or other materials.

**6.4 Tray Aerator:** Similar to a packed tower, this type of aeration device uses stacked porous shallow trays to distribute the water in thin sheets. Air is generally passed through perpendicularly to the trays.

**6.5 Diffused Aeration:** An aeration process in which compressed air is introduced into the bottom of a water basin through a two-dimensional matrix of microporous air ports.

**6.6 Spray Aerator:** An aeration process in which air is introduced into water by rapidly agitating the water surface with a mechanical mixer, causing a spray of water at the surface.

**6.7 Membrane Air Stripper:** An air stripping process in which the air to water contact is provided in the pores of a microporous hydrophobic gas permeable membrane. Water passes through the lumen of the membrane hollow fibers while air is passed through the membrane air stripper module on the exterior of the membrane fibers.

**6.8 Water Loading Rate or Liquid Loading Rate (L):** Volume of water entering the air



stripper per unit time, normalized by the cross-sectional area of the air stripper. The water loading rate has units of volume per area per time:  $\text{m}^3/(\text{m}^2 \times \text{sec})$  or  $\text{ft}^3/(\text{ft}^2 \times \text{sec})$ .

- 6.9 Air Loading Rate or Gas Loading Rate (G):** Volume of air entering the air stripper per unit time, normalized by the cross-sectional area of the air stripper. The air loading rate has units of volume per area per time:  $\text{m}^3/(\text{m}^2 \times \text{sec})$  or  $\text{ft}^3/(\text{ft}^2 \times \text{sec})$ .
- 6.10 Air/Water Ratio (A/W):** The ratio of the air loading rate to the water loading rate. The air to water ratio is dimensionless. ( $A/W = G/L$ ).
- 6.11 Henry's Law Coefficient (H):** Dimensionless ratio of the mass concentration of a given VOC in air to the mass concentration in water present at equilibrium between the two phases.
- 6.12 Stripping Factor (S):** Dimensionless expression which is equal to the product of the air to water ratio and the Henry's Law coefficient of the VOC of interest.
- 6.13 Removal Efficiency:** Percent removal of a contaminant (VOC) of interest.

or,

$$R = [1 - (C_{\text{feed}} - C_{\text{fin}})/C_{\text{feed}}] \times 100\%$$

- 6.14 Channeling:** Flow of water in channels formed along the media surface due to low water flow rate, which causes a reduced area for contact of air and water.
- 6.15 Flooding:** Holdup of water in the air stripper due to high air loading rate.
- 6.16 Biofouling:** Buildup of biological material on the packing material, resulting in increased air pressure drop.
- 6.17 Scaling:** Buildup of precipitated solids on the packing material, resulting in increased air pressure drop.

## **7.0 BACKGROUND INFORMATION ON AIR STRIPPING**

Air stripping for removal of VOCs from water is strictly a mass transfer process. No chemical reaction or transformation of the VOC occurs. Air stripping equipment is designed to provide a large surface area for contact between the water and VOC-free air, allowing VOCs to transfer from the water to the air in response to a concentration gradient between the two phases. Maximum mass transfer will occur in an air stripper that provides the greatest possible interface for contact between the phases, and increases the mass transfer coefficient in the water phase by providing turbulent flow conditions.

Theories of VOC transfer in air stripping are well known (e.g. Dvorak, et al. 1996), especially in packed tower aerators (e.g. Kavanaugh and Trussell, 1980; Ball et al., 1984). Other air stripping

equipment, though not as thoroughly studied, can also be well understood using mass transfer theory (e.g. membrane air stripping (Zander et al., 1986); cascade crossflow air stripping (Verma et al., 1994); surface aerators (Parker et al., 1996)).

In all cases two-film theory can be used to describe the resistance to mass transfer encountered by a VOC molecule in transferring from one phase to the other as the sum of the individual resistances to mass transfer in each phase. The overall resistance to mass transfer ( $1/K_L a$ ) is given by:

$$1/K_L a = 1/k_L a + 1/H k_G a$$

where  $K_L$  is the overall mass transfer rate coefficient based on the water phase driving force,  $k_L$  is the water side mass transfer coefficient, and  $k_G$  is the gas phase mass transfer coefficient. The term 'a' in each of the above expressions is the interfacial area between water and air per unit volume of the aerator. Each of the mass transfer coefficients, as well as the interfacial area available for mass transfer in a given aerator, are functions of the A/W ratio provided to the aerator.

Design equations are available for the different types of aeration equipment. For the example of packed tower aeration, the depth of tower packing necessary to provide a desired removal efficiency is calculated from a mass balance over a control volume (Hines and Maddox, 1985).

$$\text{Depth} = L/K_L a [S/(S-1)] \ln\{1/S + [(S-1)/S] (C_{\text{feed}}/C_{\text{fin}})\}$$

where,  $L$  = water loading rate

$S$  = stripping factor

$C_{\text{feed}}$  = mass concentration of the VOC of interest in the feed water

$C_{\text{fin}}$  = mass concentration of the VOC of interest in the finished water

Thus in air stripping, removal efficiency is a function of the stripping factor,  $S$ , and the overall mass transfer coefficient  $K_L a$ . More precisely, removal efficiency is a function of the air and water loading rates to the equipment and the Henry's Law coefficient of the VOC of interest.

For a given set of air and water loading rates, verification of a certain removal efficiency for a VOC with a Henry's Law coefficient  $H = H_1$ , ensures equal or greater removal efficiency for all VOCs with  $H$  greater than  $H_1$ . Similarly, verification of a certain removal efficiency for a VOC at a given set of air and water loading rates, ensures equal or greater removal efficiency for that VOC at a higher air loading rate and the given water loading rate (assuming flooding does not occur). Finally, verification of a given removal efficiency for a given VOC at a temperature  $T = T_1$ , ensures equal or greater removal efficiency for that VOC at any  $T$  greater than  $T_1$ .

For mechanical air stripping equipment such as a spray aerator, verification of removal efficiency for a VOC with a Henry's law coefficient of  $H = H_1$ , ensures equal or greater removal efficiency for all VOCs with  $H$  greater than  $H_1$ , and equal or greater removal efficiency of the given VOC at any motor speed greater than that tested.

As each type of air stripping equipment allows calculation of an estimated removal efficiency using

design equations, operating conditions and the VOCs to be tested can and should be judiciously chosen to minimize unnecessary testing.

## **8.0 TASK 1: CHARACTERIZATION OF FEED WATER**

### **8.1 Introduction**

This task is needed to document the chemical and microbiological characteristics of the feed water.

### **8.2 Experimental Objective**

The objective of this task is to document the water quality characteristics of the feed water to the air stripping system, including the initial mass concentration of VOCs of interest in the feed water and potentially including the calculated potential for precipitative scaling, and a measured indication of the potential for microbiological fouling.

### **8.3 Work Plan**

This task can be accomplished by using approved analytical measurements obtained from certified third party sources (i.e. United States Geological Society (USGS), EPA, State Laboratories, Municipal Laboratories). The specific parameters needed to characterize the water will depend on the equipment being tested, but information on the following characteristics should be compiled:

- VOCs of interest and their respective mass concentration in the feed water and water temperature.

It is recommended that additional parameters be measured to characterize the water, including:

- Dissolved oxygen, pH and turbidity to establish physical characterization;
- Total Dissolved Solids, Total Alkalinity, Total Hardness, Scaling Potential, Iron, and Manganese to establish inorganic chemical characterization; and
- Heterotrophic Plate Count and Total Sulfur to establish the potential for microbiological fouling.

A brief description of the water source shall be provided to aid in interpretation of feed water characteristics.

Several of the water quality parameters described in this task shall be measured on-site by the NSF-qualified Field Testing Organization. Analysis of the remaining water quality parameters shall be performed by a State certified, third-party accredited (e.g. NSF), or EPA accredited analytical laboratory. The methods to be used for measurement of water quality parameters in the field are described in Tables 1 and 2. Where appropriate, the Standard Methods reference numbers and EPA method numbers for water quality parameters are provided for both the field and laboratory analytical procedures.

For the water quality parameters requiring analysis at an off-site laboratory, water samples shall be collected in appropriate containers (containing preservatives as applicable) prepared by the State certified, third-party accredited (e.g. NSF), or EPA accredited laboratory. These samples shall be preserved, stored, shipped and analyzed in accordance with appropriate procedures and holding times, as specified by the analytical lab.

#### 8.4 Analytical Schedule

In many cases, sufficient water quality data may already exist to permit making a determination of the suitability of a water source for use as feed water in an air stripping Verification Testing Program. In the absence of such data, a set of these measurements performed by an approved lab will suffice for this task. Table 1 outlines the required parameters to be measured and the methods to be used for analysis. Table 2 outlines the recommended parameters to be measured and their respective analytical methods.

**Table 1**  
**Required Analytical Parameters and Methods**

Parameter	Facility	Standard Method <sup>a</sup>	EPA Method <sup>b</sup>
VOCs (specify)	Lab	6210 C	502.2 / 524.2
Temperature	On-Site	2550 B	

**Notes:**

<sup>a</sup> APHA, AWWA, WEF, 1992 (or later).

<sup>b</sup> EPA Methods Source: EPA Office of Ground and Drinking Water. EPA Methods are available from the National Technical Information Service (NTIS).

Samples of feed waters shall be collected for analysis of indigenous bacterial densities by heterotrophic plate count (HPC). Collected samples shall be placed in a cooler with blue ice to be shipped with an internal cooler temperature of approximately 2-8°C to the State certified, third-party accredited (e.g. NSF), or EPA accredited analytical laboratory. Samples shall be processed for analysis by the State certified, third-party accredited (e.g. NSF), or EPA accredited laboratory within 24 hours of collection. The laboratory shall then keep the samples at a temperature of approximately 2-8°C until initiation of analysis. HPC densities will be reported as colony forming units per milliliter (cfu/mL).

**Table 2**  
**Recommended Analytical Parameters and Methods**

<b>Parameter</b>	<b>Facility</b>	<b>Standard Method<sup>a</sup></b>	<b>EPA Method<sup>b</sup></b>
pH	On-Site	4500-H <sup>+</sup>	150.1 / 150.2
Turbidity	Lab	2130 B	180.1
Dissolved Oxygen	Lab	4500-O	
Total Dissolved Solids	Lab	2540 C	
Total Alkalinity	Lab	2320 B	
Total Hardness	Lab	2340 C	
Iron	Lab	3113 B	200.7 / 200.8 / 200.9
Manganese	Lab	3113 B	200.7 / 200.8 / 200.9
Total Sulfide	Lab	4500-S <sup>2-</sup>	
Heterotrophic Plate Count	Lab	9215 B	
Scaling Potential	Calculated	Langlier's Index	

**Notes:**

<sup>a</sup> APHA, AWWA, WEF, 1992 (or later).

<sup>b</sup> EPA Methods Source: EPA Office of Ground and Drinking Water. EPA Methods are available from the National Technical Information Service (NTIS).

## **8.5 Evaluation Criteria and Minimum Reporting Requirements**

Feed water quality will be evaluated in the context of the Manufacturer's statement of performance capabilities. The feed water should challenge the capabilities of the equipment but should not be beyond the range of water quality suitable for treatment using the equipment specified. The Langelier Index or another index which quantifies the scaling potential for the feed water should be calculated and reported along with the raw data collected as part of this task.

## **9.0 TASK 2: VERIFICATION TESTING**

### **9.1 Introduction**

Package air stripping equipment shall be operated for Verification Testing purposes. VOC removal efficiency by the air stripping equipment will be tested for the stated VOCs of interest.

## **9.2 Experimental Objectives**

The objective of this task is to operate the equipment provided by the Manufacturer and to assess its ability to meet the water quality goals and any other performance characteristics specified by the manufacturer in the statement of performance capabilities.

## **9.3 Work Plan**

This task shall be performed concurrently with Task 3: Operating Conditions and System Performance.

For this task the Manufacturer or Field Testing Organization shall specify the operating conditions to be evaluated in this Verification Testing Plan and shall supply written procedures on the operation and maintenance of the air stripping system. The Field Testing Organization shall specify the air and water loading rates at which the equipment is to be verified, and the VOCs which should be measured as part of the verification testing.

After set-up and shakedown of the air stripping equipment, operation should be established at the air and water loading rates for the condition to be verified. The air stripping equipment shall be operated under these steady state conditions for a minimum of eight hours per operating condition to be verified.

Additional operational conditions may be verified using the same equipment in successive periods as long as the verification period does not extend beyond the time period of coldest operating temperature for verification purposes. For each testing period the air and water loading rates to be tested shall be explicitly stated prior to testing.

This Verification Testing Plan has been designed with the aim of balancing cost of verification with benefits of testing over a wide range of operating conditions. It shall be understood that beyond the operational characteristics specifically tested, air stripping equipment operation which occurs at an air loading rate higher than specifically tested for a given water loading rate shall also constitute a verifiable condition, as long as the condition does not lead to flooding.

Many of the water quality parameters described in this task shall be measured on-site by the NSF-qualified Field Testing Organization. Analysis of the remaining water quality parameters shall be performed by a State certified, third-party accredited (e.g. NSF), or EPA accredited analytical laboratory. The methods to be used for measurement of water quality parameters in the field are described in Table 1 with additional recommended parameters in Table 2. Where appropriate, the Standard Methods reference numbers and EPA method numbers for water quality parameters are provided for both the field and laboratory analytical procedures.

For the water quality parameters requiring analysis at an off-site certified or accredited laboratory, water samples shall be collected in appropriate containers (containing preservatives as applicable) prepared by the State certified, third-party accredited (e.g. NSF), or EPA accredited off-site laboratory. These samples shall be preserved, stored, shipped and analyzed in accordance with appropriate procedures and holding times, as specified by the analytical lab.

## 9.4 Analytical Schedule

Samples shall be collected at least three times per operational condition and at least two hours apart from the feed water and the finished water and analyzed to determine the mass concentration of the VOCs of interest. The temperature of the feed water and finished water shall be measured and documented immediately after samples for VOC analysis are collected. The analytical methods are provided in Table 3.

**Table 3**  
**Testing Schedule and Methods for Verification Testing**

Parameter	Location	Facility	Method
VOCs (specified)	Feed water	Lab	Standard Methods <sup>a</sup> 6210 C or EPA Method <sup>b</sup> 524
VOCs (specified)	Finished water	Lab	Standard Methods <sup>a</sup> 6210 C or EPA Method <sup>b</sup> 524
Temperature	Feed water	On-Site	Standard Methods 2550 B
Temperature	Finished water	On-Site	Standard Methods 2550 B

**Notes:**

<sup>a</sup> APHA, AWWA, WEF, 1992 (or later).

<sup>b</sup> EPA Methods Source: EPA Office of Ground and Drinking Water. EPA Methods are available from the National Technical Information Service (NTIS).

## 9.5 Evaluation Criteria and Minimum Reporting Requirements

The goal of this task is to operate the equipment under steady state conditions at each verifiable operating condition. Data shall be provided to substantiate operation at steady state. The concentration of each VOC of interest in the feed water and the finished water shall be reported for each condition, along with the temperature of the feed and finished water. In addition, all operational data collected shall be reported.

## 10.0 TASK 3: OPERATING CONDITIONS AND SYSTEM PERFORMANCE

### 10.1 Introduction

During each condition of Verification Testing, and at least twice during each day, operating conditions shall be documented. This shall include a statement of any pretreatment performed on the feed water, documentation of air pressure drop through the equipment, flow measurements, visual inspection of equipment, and any maintenance activities performed.

## **10.2 Experimental Objectives**

The objective of this task is to accurately and fully document the operating conditions that are applied during treatment and the performance of the air stripping equipment. This task is intended to result in data that describe the operation of the equipment and data that can be used to develop cost estimates for operation of the equipment.

## **10.3 Work Plan**

This task shall be performed concurrently with Task 2: Verification Testing.

Measurement of feed water flow rate, air flow rate, and air pressure entering the air stripper shall be performed at a minimum of two times per day. For packed tower and tray aerator systems, air pressure exiting the system shall also be measured two times per day, within 15 minutes of measurement of the influent air pressure.

In an attempt to calculate costs for operation of air stripping equipment, power costs for operation of the equipment shall also be closely monitored and recorded by the Field Testing Organization during the testing period(s). Power usage shall be estimated by the following requirements: pumping requirements, size of pumps, nameplate voltage, current draw, power factor, motor power usage for fans or mixers, etc.

## **10.4 Evaluation Criteria and Minimum Reporting Requirements**

Where applicable, the data developed from this task will be compared to statement of performance capabilities. If no relevant statement of performance capability exists, results of operating and performance data will be tabulated for inclusion in the Verification Report.

# **11.0 TASK 4: FINISHED WATER QUALITY**

## **11.1 Introduction**

Water quality data shall be collected for the finished water as was performed for the feed water and as shown in Table 1. At a minimum, the required sampling shown in Table 1 shall be observed by the Field Testing Organization on behalf of the Manufacturer. Recommended tests from Table 2 may also be included. Water quality goals and target removal goals for the air stripping equipment shall be recorded in the Field Operations Document.

## **11.2 Experimental Objectives**

The objective of this task is to assess the ability of the air stripping equipment to meet the water quality goals specified by the Manufacturer and to identify any potential adverse effect on the water quality.



### 11.3 Work Plan

Several of the water quality parameters described in this task shall be measured on-site by the NSF-qualified Field Testing Organization (refer to Table 2). Analysis of the remaining water quality parameters shall be performed by a State certified, third-party accredited (e.g. NSF), or EPA accredited analytical laboratory. The methods to be used for measurement of water quality parameters in the field are described in Table 1. Where appropriate, the Standard Methods reference numbers and EPA method numbers for water quality parameters are provided for both the field and laboratory analytical procedures.

For the water quality parameters requiring analysis at an off-site certified or accredited laboratory, water samples shall be collected in appropriate containers (containing preservatives as applicable) prepared by the State certified, third-party accredited (e.g. NSF), or EPA accredited off-site laboratory. These samples shall be preserved, stored, shipped and analyzed in accordance with appropriate procedures and holding times, as specified by the analytical lab.

### 11.4 Analytical Schedule

At least once in each verification test the finished water shall be characterized by measurement of the following water quality parameters (as indicated also in Table 2). The specific parameters needed to characterize the water will depend on the equipment being tested, but information on the following characteristics are also recommended for compilation:

- Dissolved oxygen, pH and turbidity to establish any changes in physical characterization relative to the feed water;
- Total Dissolved Solids, Total Alkalinity, Total Hardness, Corrosivity, Iron, and Manganese to establish mass balances on the inorganic parameters; and
- Heterotrophic Plate Count and Total Sulfide to indicate the likelihood of biological fouling.

Additional sampling and data collection may be performed at the discretion of the Field Testing Organization. Sample collection frequency and protocol shall be defined by the Field Testing Organization in the Field Operations Document.

Samples of feed waters shall be collected for analysis of indigenous bacterial densities by heterotrophic plate count (HPC). Collected samples shall be placed in a cooler with blue ice to be shipped with an internal cooler temperature of approximately 2-8°C to the State certified, third-party accredited (e.g. NSF), or EPA accredited analytical laboratory. Samples shall be processed for analysis by the State certified, third-party accredited (e.g. NSF), or EPA accredited laboratory within 24 hours of collection. The laboratory shall then keep the samples at a temperature of approximately 2-8°C until initiation of analysis. HPC densities will be reported as colony forming units per milliliter (cfu/mL).

## **11.5 Evaluation Criteria and Minimum Reporting Requirements**

Where applicable, the data from this task will be utilized to determine if scaling or biofouling has occurred in the air stripping equipment, and as feasible perform a mass balance to determine the extent of that fouling. Any loss of inorganic material shall be interpreted as scaling and increase in biological material shall be interpreted as fouling and must be reported in the Verification Report.

## **12.0 TASK 5:DATA MANAGEMENT**

### **12.1 Introduction**

The data management system used in the verification testing program shall involve the use of computer spreadsheets and manual recording of operational parameters for the air stripping equipment on a daily basis.

### **12.2 Experimental Objectives**

The objective of this task is to establish a viable structure for the recording and transmission of field testing data such that the Field Testing Organization provides sufficient and reliable operational data to the NSF for verification purposes.

### **12.3 Work Plan**

The following protocol has been developed for data handling and data verification by the Field Testing Organization. Where possible, a Supervisory Control and Data Acquisition (SCADA) system should be used for automatic entry of testing data into computer databases. Specific parcels of the computer databases for operational and water quality parameters should then be downloaded by manual importation into spreadsheet software. These specific database parcels shall be identified based upon discrete time spans and monitoring parameters. In spreadsheet form, the data shall be manipulated into a convenient framework to allow analysis of equipment operation. At a minimum, backup of the computer databases to diskette should be performed on a weekly basis.

In the case when a SCADA system is not available, field testing operators shall record data and calculations by hand in laboratory notebooks. (Daily measurements shall be recorded on specially-prepared data log sheets as appropriate.) The laboratory notebook shall provide carbon copies of each page. The original notebooks shall be stored on-site; the carbon copy sheets shall be forwarded to the project engineer of the Field Testing Organization at least once per week during each testing period. This protocol will not only ease referencing the original data, but offer protection of the original record of results. Pilot operating logs shall include a description of the air stripping equipment (description of test runs, names of visitors, description of any problems or issues, etc.); such descriptions shall be provided in addition to experimental calculations and other items.

The database for the project shall be set up in the form of custom-designed spreadsheets. The spreadsheets shall be capable of storing and manipulating each monitored water quality and operational

parameter from each task, each sampling location, and each sampling time. All data from the laboratory notebooks and data log sheets shall be entered into the appropriate spreadsheet. Data entry shall be conducted on-site by the designated field testing operators. All recorded calculations shall also be checked at this time. Following data entry, the spreadsheet shall be printed out and the print-out shall be checked against the handwritten data sheet. Any corrections shall be noted on the hard-copies and corrected on magnetic storage (e.g. disk), and then a corrected version of the spreadsheet shall be printed out. Each step of the verification process shall be initialed by the field testing operator or engineer performing the entry or verification step.

Each experiment shall be assigned a run number which will then be tied to the data from that experiment through each step of data entry and analysis. As samples are collected and sent to State certified, third-party accredited (e.g. NSF), or EPA accredited laboratories, the data shall be tracked by use of the same system of run numbers. Data from the outside laboratories shall be received and reviewed by the field testing operator. These data shall be entered into the data spreadsheets, corrected, and verified in the same manner as the field data.

## **13.0 TASK 6: QUALITY ASSURANCE/QUALITY CONTROL**

### **13.1 Introduction**

Quality assurance and quality control of the operation of the air stripping equipment and the measured water quality parameters shall be maintained during the verification testing program.

### **13.2 Experimental Objectives**

The objective of this task is to maintain strict QA/QC methods and procedures during the Equipment Verification Testing Program. Maintenance of strict QA/QC procedures is important, in that if a question arises when analyzing or interpreting data collected for a given experiment, it will be possible to verify exact conditions at the time of testing.

### **13.3 Work Plan**

Equipment flow rates and associated signals should be documented and recorded on a routine basis. A routine daily visual check during testing shall be established to verify that each piece of equipment or instrumentation is operating properly. Air and water flow rates shall be measured and documented. In-line monitoring equipment such as flowmeters, etc. shall be checked to confirm that the readout matches with the actual measurement (i.e. flow rate) and that the signal being recorded is correct. The items listed are in addition to any specified checks outlined in the analytical methods.

### **13.4 On-Site Analytical Methods**

The analytical methods utilized in this study for on-site monitoring of feed water and filtrate water quality are described in the section below. Use of either bench-top or in-line field analytical equipment will be acceptable for the verification testing; however, in-line equipment is recommended for ease of

operation. Use of in-line equipment is also preferable because it limits the introduction of error and the variability of analytical results generated by inconsistent sampling techniques.

#### **13.4.1 Temperature**

Readings for temperature shall be conducted in accordance with Standard Methods 2550. Raw water temperatures shall be obtained at least once daily. The thermometer shall have a scale marked for every 0.1 °C, as a minimum, and should be calibrated weekly against a precision thermometer certified by the National Institute of Standards and Technology (NIST). (A thermometer having a range of -1 °C to +51 °C, subdivided in 0.1 °C increments would be appropriate for this work.)

#### **13.4.2 pH (Optional)**

Analyses for pH shall be performed according to Standard Method 4500-H<sup>+</sup>. A 2 point calibration of the pH meter used in this study shall be performed once per day when the instrument is in use. Certified pH buffers in the expected range shall be used. The pH probe shall be stored in the appropriate solution defined in the instrument manual. Transport of carbon dioxide can confound pH measurements in poorly buffered waters. If this is a problem, measurement of pH in a confined vessel is recommended.

#### **13.4.3 Turbidity (Optional)**

Turbidity analyses shall be performed in accordance with Standard Method 2130 with a bench-top turbidimeter. (An in-line turbidimeter is acceptable, but unnecessary for this task.) The turbidimeter shall be calibrated within the expected range of sample measurements at the beginning of verification testing and on a weekly basis thereafter using primary turbidity standards of 0.1, 0.5 and 3.0 NTU. The turbidimeter shall be recalibrated after being shut off and re-started.

The method of collecting grab samples will consist of running a slow, steady stream from the sample tap, triple-rinsing a dedicated sample beaker in this stream, allowing the sample to flow down the side of the beaker to minimize bubble entrainment, double-rinsing the sample vial with the sample, carefully pouring from the beaker down the side of the sample vial, wiping the sample vial clean, inserting the sample vial into the turbidimeter, and recording the measured turbidity. For the case of cold water samples which cause the vial to fog, allow the vial to warm slightly by submersing partially into a warm water bath for approximately thirty seconds.

#### **13.4.4 Dissolved Oxygen (Optional)**

Dissolved oxygen analyses shall be performed in accordance with Standard Method 4500-O with a field dissolved oxygen meter or a field titration. Calibrate either method as described in Standard Methods (APHA, AWWA, WEF, 1992).

Avoid entraining or dissolving atmospheric oxygen during sampling. In sampling from a line under pressure, attach a glass or rubber tube to the tap and extend to the bottom of the sample bottle. Let the bottle overflow two or three times its volume and stopper the bottle.

### **13.5 Chemical and Biological Samples Shipped Off-Site for Analysis**

#### **13.5.1 VOCs**

Samples for measurement of VOC concentrations shall be collected headspace-free in 25- or 40-mL glass bottles equipped with a screw cap with a hole in the center and TFE-lined silicone septa supplied by the State certified, third-party accredited (e.g. NSF), or EPA accredited laboratory. Samples shall be collected in duplicate, stored at 4 °C in an atmosphere free of organic solvent vapors, and shipped at 4 °C to the analytical laboratory. Field blanks shall be collected with the samples and subjected to storage and shipping as performed for the analytical samples. Analysis shall occur within 14 days of sampling.

#### **13.5.2 Chemical Analysis: Total Dissolved Solids, Alkalinity, and Hardness (Optional Parameters)**

Samples shall be collected headspace-free in polyethylene or borosilicate glass bottles and capped tightly. Store and ship at 4 °C. Analyze as soon as possible and in no case store samples more than 7 days. Bring samples to room temperature prior to analysis.

#### **13.5.3 Chemical Analysis: Iron and Manganese (Optional Parameters)**

Samples shall be collected in acid-rinsed polypropylene or linear polyethylene containers supplied by the State certified, third-party accredited (e.g. NSF), or EPA accredited analytical laboratory. Preserve samples immediately after sampling with concentrated high-purity nitric acid to a pH less than 2. Usually 1.5 mL concentrated HNO<sub>3</sub> per liter of sample is sufficient. Store and ship at 4 °C, and analyze as soon as possible, but within 6 months of sampling.

#### **13.5.4 Chemical Analysis: Total Sulfide (Optional)**

Samples shall be collected with minimum aeration in polypropylene or glass bottles containing zinc acetate solution provided by the State certified, third-party accredited (e.g. NSF), or EPA accredited laboratory. Fill the bottle completely and add NaOH dropwise to a pH greater than 9. Store and ship at 4 °C, and analyze as soon as possible, but within 28 days of sampling.

#### **13.5.5 Microbial Analysis: Heterotrophic Plate Count (Optional)**

Microbiological samples shall be collected in carefully cleaned and sterilized bottles or bags supplied by the State certified, third-party accredited (e.g. NSF), or EPA accredited analytical laboratory. Analyze samples as soon as possible, but within 24 hours of sampling. Hold and ship samples at or below 4 °C, but do not freeze.

## **14.0 TASK 7: EFFECT OF SCALING AND BIOFOULING (RECOMMENDED)**

### **14.1 Introduction**

Long-term performance of the air stripping equipment involving the effect of scaling and/or biofouling on the VOC removal efficiency is recommended to be determined in a 30-day continuous operation during the warmest season of the year.

### **14.2 Experimental Objectives**

The objective of this task is to quantify the reduction of VOC removal efficiency over a continuous 30-day operating period for a given feed water.

### **14.3 Work Plan**

This task shall be performed concurrently with Task 3: Operating Conditions and System Performance.

For this task the Manufacturer or Field Testing Organization shall specify the operating condition to be utilized for a 30-day continuous operation during the warmest season of the year. The Field Testing Organization shall specify the air and water loading rates at which the equipment is to be verified, and the VOCs which should be measured as part of the verification testing.

After set-up and shakedown of the air stripping equipment, operation should be established at the air and water loading rates for the condition to be verified. The air stripping equipment shall be operated under these steady state conditions for a minimum of 30 days.

Analysis of the concentration of VOCs in the feed water and the finished water shall be performed by a state certified, third-party accredited (e.g. NSF), or EPA accredited laboratory. Water samples shall be collected in appropriate containers prepared by the state certified, third-party accredited (e.g. NSF), or EPA accredited off-site laboratory. These samples shall be preserved, stored, shipped and analyzed in accordance with appropriate procedures and holding times, as specified by the analytical lab.

### **14.4 Analytical Schedule**

Samples shall be collected at least every third day from the feed water and the finished water and analyzed to determine the mass concentration of the VOCs of interest.

### **14.5 Evaluation Criteria and Minimum Reporting Requirements**

The goal of this task is to quantify the VOC removal efficiency over a longer operation period. Data should be provided to verify operation for at least 30 days. The concentration of each VOC of interest in the feed water and the finished water shall be reported for at least every third day, along with the temperature of the feed and finished water. Removal efficiency for each VOC shall be calculated for each set of samples. In addition, all operational data collected shall be reported.

## **15.0 OPERATION AND MAINTENANCE MANUAL CRITERIA - AIR STRIPPING EQUIPMENT**

The Field Testing Organization shall obtain the Manufacturer-supplied Operations and Maintenance (O&M) Manual to evaluate the instructions and procedures for their applicability during the verification testing period. The following are recommendations for criteria for O&M Manuals for package plants employing air stripping for removal of VOCs.

### **15.1 Maintenance**

The Manufacturer should provide readily understood information on the recommended or required maintenance schedule for each piece of operating equipment such as:

- pumps
- blowers
- valves
- motors
- instruments, such as an in-line turbidimeter
- flow measurement devices

The manufacturer should provide readily understood information on the recommended or required maintenance of non-mechanical or non-electrical equipment such as:

- tanks and basins
- tower materials
- tower packing or tray materials
- membrane modules.

### **15.2 Operation**

The Manufacturer should provide readily understood recommendations for procedures related to proper operation of the package plant equipment. Among the operating aspects that should be discussed are:

- Procedures for setting and measuring air and water flow rates
- Proper cleaning procedures for all equipment provided
- Proper operation of any pretreatment equipment deemed necessary.

## **16.0 REFERENCES**

APHA, AWWA, WEF (1992) *Standard Methods for the Examination of Water and Wastewater, 18th edition*, American Public Health Association, Washington, DC.

Ball, W.P., Jones, M.D. and Kavanaugh, M.C. (1984) "Mass Transfer of Volatile Organic Compounds in Packed Tower Aeration," *Journal Water Pollution Control Federation*, Vol. 56, No. 2, pp. 127-136.

Dvorak, B.I., Lawler, D.F., Fair, J.R. and Handler, N.E. (1996) "Evaluation of the Onda Correlations for Mass Transfer with Large Random Packings," *Environmental Science and Technology*, Vol. 30, No. 3, pp. 945-953.

Hines, A.L. and Maddox, R.N. (1985) *Mass Transfer Fundamentals and Applications*, Prentice Hall, Englewood Cliffs, NJ.

Kavanaugh, M.C. and Trussell, R.R. (1980) "Design of Aeration Towers to Strip Volatile Contaminants from Drinking Water," *Journal AWWA*, Vol. 72, No. 12, pp. 684.

Parker, W.J., Monteith, H.D., Bell, J.P. and Melcer, H. (1996) "A Field Scale Evaluation of the Airstripping of Volatile Organic Compounds by Surface Aerators," *Water Environment Research*, Vol. 68, No. 7, pp. 1132-1139.

Verma, S., Valsaraj, K.T., Wetzel, D.M. and Harrison, D.P. (1994) "Direct comparison of Countercurrent and Cascade Crossflow Air Stripping Under Field Conditions," *Water Research*, Vol. 28, No. 11, pp. 2253-2261.

Zander, A.K., Semmens, M.J. and Narbaitz, R.M. (1989) "Removing VOCs by Membrane Stripping," *Journal AWWA*, Vol. 81, No. 11, pp. 76-81.